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QUANTIFYING VINE MEALYBUG (*PLANOCOCCUS FICUS*) SPATIOTEMPORAL DYNAMICS: ASSESSING INVASION RISK TO REFINE MANAGEMENT STRATEGIES

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INTRODUCTION

Geospatial analyses and niche-based/species distribution modeling have previously been used to characterize plant, aquatic invertebrate, amphibian, and insect invasions. Results of these and similar investigations have been applied, with varying degrees of success, to develop early detection strategies, identify and prioritize management in high risk areas, and minimize monitoring expenditures (Thuiller et al. 2005, Bradley et al. 2010, Venette et al. 2010, Jiménez-Valverde et al. 2011, Vincente et al. 2016). An intriguing possibility is that information gained from geospatial analyses of invader spread and niche-based/species distribution modeling of suitable habitat for invaders may be used to simulate invader dispersal and predict invader distributions. Ensuing predictions of invader distributions could then guide detection and management efforts, as well as be evaluated and refined using field-collected data on invader occurrence. Here we use such tools to improve response to an important invasive insect in California, the vine mealybug (VMB; *Planococcus ficus* [Signoret]).

The vine mealybug is a severe vineyard pest that contaminates fruit, debilitates vines, and transmits plant pathogens such as *Grapevine leafroll-associated virus-3* (Daane et al. 2012; Almeida et al. 2013). Management of VMB has proven challenging and often requires the use of multiple tactics, including biological control, mating disruption and insecticides (Daane et al. 2008). Management can be particularly complicated in coastal wine grape-growing regions where climatic conditions are favorable and Argentine ants (*Linepithema humile* [Mayr]) disrupt biological control (Daane et al. 2007, Gutierrez et al. 2008). Management costs may range from $300 to $500 per acre, per year; and due to the aggressive nature of VMB populations, these practices cannot be neglected.

Vine mealybug was first reported in California from vines in the Coachella Valley (Gill 1994) and soon spread throughout much of the state, likely on infested nursery stock (Haviland et al. 2005). It is currently found in most California grape-growing regions (Godfrey et al. 2002; Daane et al. 2004a, 2004b). However, despite the continued expansion of VMB in California, its current distribution in Napa County and areas at risk of VMB introduction in this region are not well characterized.

OBJECTIVES

Given the ongoing expansion of the vine mealybug (VMB; *Planococcus ficus*) in California and continued risk of its introduction into new areas, a better understanding is needed of what is driving its invasion. The overall goal of this research is to <u>characterize the factors associated with VMB establishment and spread in Northern California vineyards</u>, which will be addressed via the following objectives:

1) Quantify the spatiotemporal patterns in VMB occurrence to identify invasion hot spots and patterns of spread

2) Characterize the landscape, climatic, and anthropogenic factors associated with current VMB occurrence to predict areas at risk to invasion

3) Validate and update predictions of VMB risk via in-field monitoring

RESULTS AND DISCUSSION

Survey data on 2012-17 VMB occurrence were acquired from the Napa County Agricultural Commissioner's Office, georeferenced relative to grid cells in the CDFA State Wide Grid System, cleaned (i.e., removal of duplicate records, filling in missing information, correction of data inconsistencies, etc.), and have been summarized in previous reports. Trapping data from 2018 will be incorporated into dataset once available.

Objective 1

Analyses of spatiotemporal trends in 2012-17 VMB occurrence are completed and have previously been reported. Recently, these analyses have been used to inform the Napa County Winegrape Pest & Disease Control District (NCWPDCD) efforts to prioritize future VMB trapping. We first identified 1 km^2 grid cells that qualified as statistical hotspots of VMB occurrence between 2012 and 17, which represent areas of VMB establishment in which continued trapping offers little value. For the rest of the study region, we extracted the habitat suitability prediction (Obj 2), and grouped cells categorically into rankings of low (suitability < 0.33), medium (0.33 > suitability < 0.66), or high (suitability > 0.66) risk (Figure 1). We then superimposed the CDFA State Wide Grid System over these risk categories to identify subgrid cells of low, medium, or high priority for future trapping efforts (Figure 2). The complete lists of CDFA subgrid cell id and ranking were provided to the NCWPDCD. Adoption of these rankings would reduce trapping requirements by approximately 20% if low, medium, and high risk cells are monitored, by 80% if medium and high are monitored, and 92% if only high risk cells are monitored.

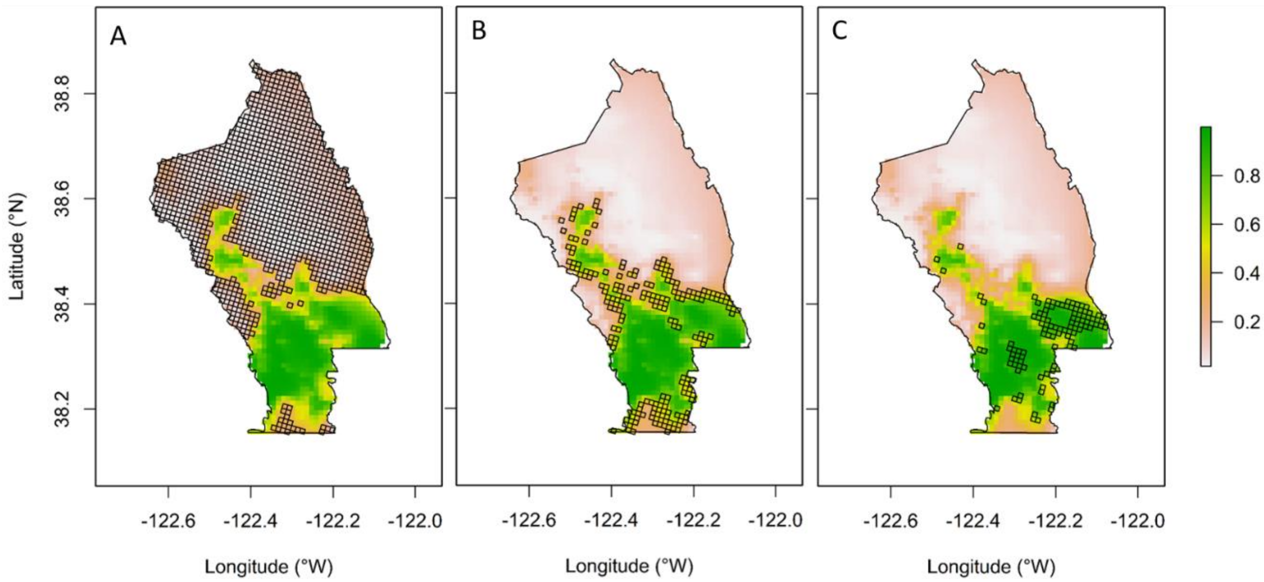

Figure 1. Location of 1 km^2 grid cells in 2012-17 superimposed over the grand ensemble prediction of habitat suitability for VMB. Panels indicate A) low, B) medium, and C) high risk 1km^2 cells.

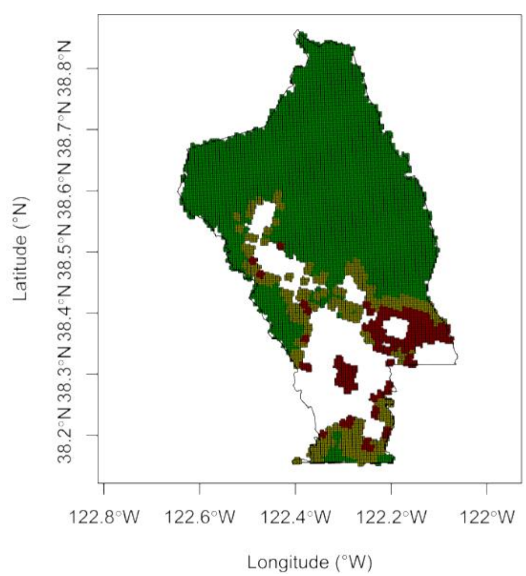

Figure 2. CDFA subgrid trapping cells categorized as low (green), medium (yellow), and high (red) priority for future VMB trapping efforts. White regions denote VMB hotspots, where additional monitoring in not warranted.

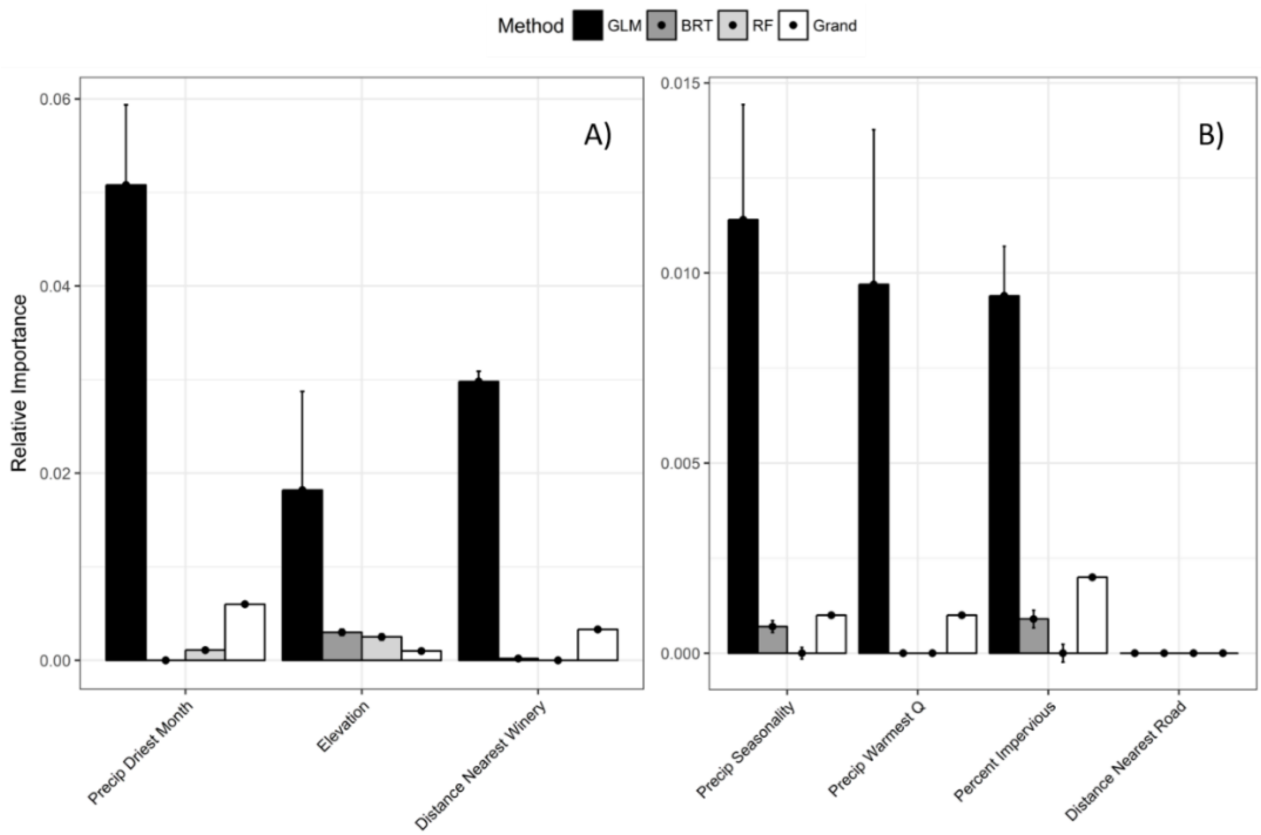

Figure 4. Relative importance of selected climatic, environmental, and anthropogenic variables in explaining VMB occurrence in Napa County. Note the different y-axis scale between panels.

Objective 2

Analyses of the landscape, climatic, and anthropogenic factors associated with current VMB occurrence are also complete. All 2012-17 records of VMB presence and absence were compiled by considering unique traps that recorded VMB detections in at least one year (presence, n = 2208) or were deployed in at least one year but never recorded a VMB detection (absence, n = 2318). Variables of interest include 19 climate variables (WorldClim layers), elevation, percent impervious surface, and trap distance to nearest road and nearest winery. We also employed spatial eigenvector filtering to generate spatial predictors that reduce the signature of spatial autocorrelation among our presence-absence data. The final, AIC-informed model was used in conjunction with generalized linear models, boosted regression trees, and random forest algorithms to assess the relative importance of each predictor variable, quantify the magnitude and directionality of each predictor-VMB relationship, and generate predictions of habitat suitability for VMB throughout Napa County.

All modeling and ensemble methods employed to predict habitat suitability for VMB in Napa County performed well (receiver operating characteristic [ROC] values > 0.8 and true skill statsistic [TSS] values > 0.6). The boosted regression tree and random forest algorithms slightly outperformed the generalized linear modeling method. The grand ensemble method was the best-performing method employed (ROC = 0.953, TSS = 0.753).

The relative importance of our selected anthropogenic, climatic, and environmental predictor variables varied among the modeling and ensemble methods employed (Figure 4). In general, the amount of precipitation in the driest month, elevation, and trap distance to nearest winery were identified as the most important predictors of VMB occurrence. Precipitation in the driest month and trap distance to nearest winery were negatively associated with VMB occurrence whereas the probability of VMB occurrence increased slightly with increasing elevation (Figure 5). Conversely, trap distance to nearest road was the least important predictor across all modeling and ensemble methods and exerted little effect on the probability of VMB occurrence.

Predictions of habitat suitability are largely congruent among method-specific ensemble predictions (Figure 6). Habitat suitability in the grand ensemble model was predicted to be greatest surrounding Napa and St. Helena, and the central-eastern portion of Napa County (Figure 7). Regions of Napa County where viticulture is largely absent, such as the northeastern portion of the county, are generally predicted to be of poor suitability.

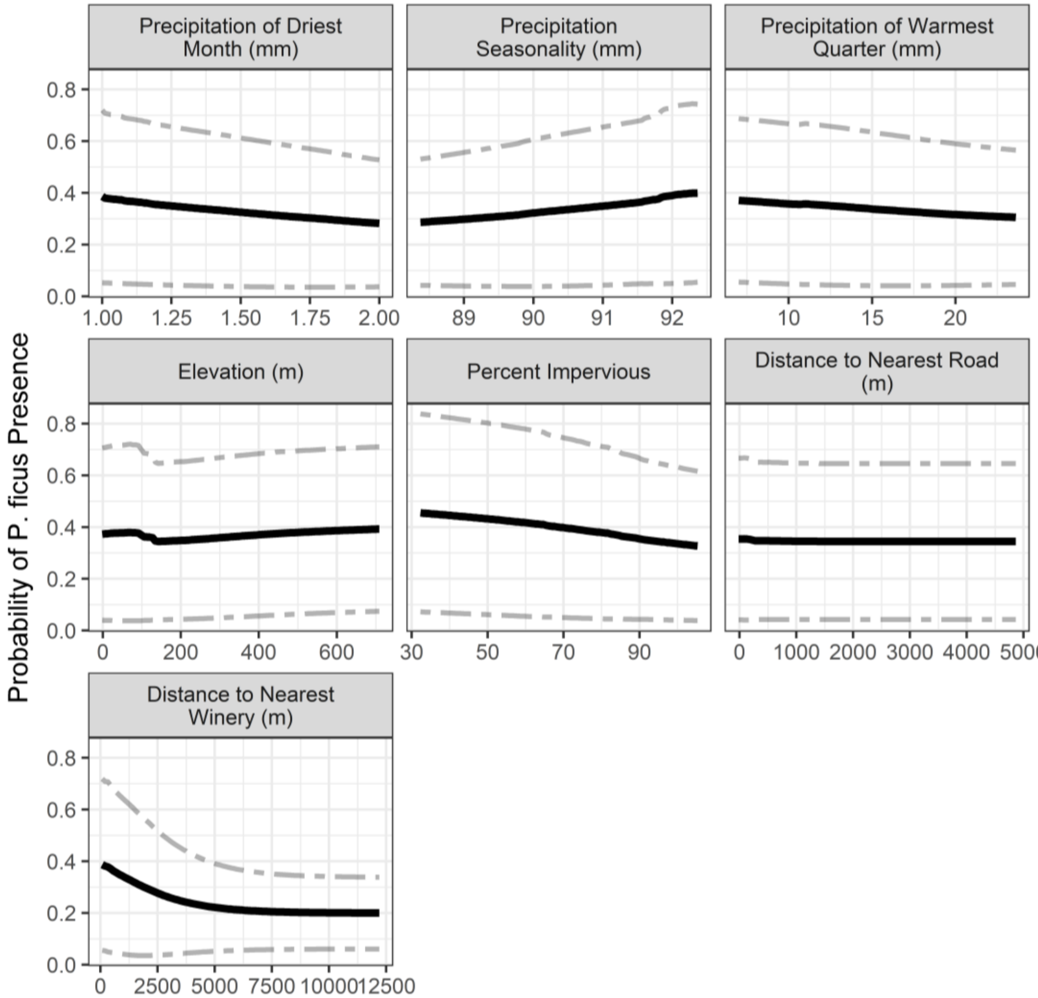

Figure 5. Mean fitted responses (solid black line) and 95% confidence interval (grey dashed line) of select landscape, climatic, and anthropogenic varaibles from grand ensemble predictions of habitat suitability.

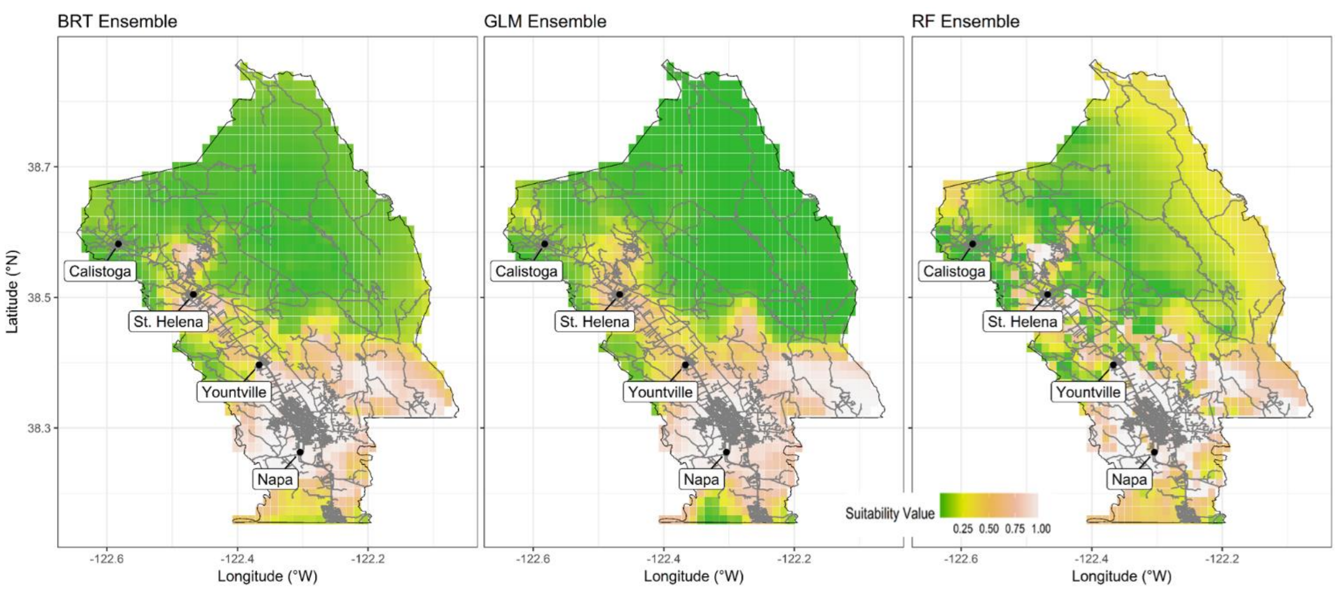

Figure 6. Method-specific ensemble predictions of habitat suitability for VMB in Napa County as produced by boosted regression tree, generalized linear model, and random forest algorithm methods.

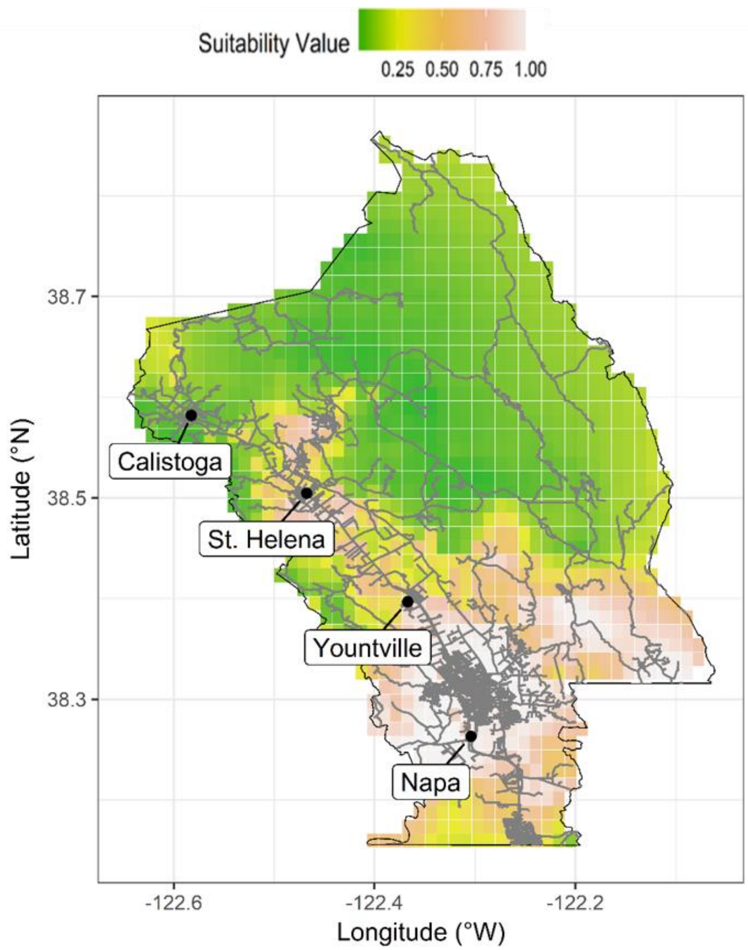

Figure 7. TSS-weighted grand ensemble prediction of habitat suitability for VMB in Napa County.

Objective 3

Work on Objective 3 is leveraging the results of Objectives 1 and 2 to evaluate the accuracy of predictions of habitat suitability and risk of VMB infestation via in-field monitoring. Currently, we are working with grapegrowers and vineyard managers to identify vineyards that remain uninfested by VMB as well as vineyards where novel VMB infestations were recently identified. So far, a total of 10 novel within-vineyard infestations have been detected or reported by grapegrowers and vineyard managers. These novel infestations are located in the area surrounding the town of Napa where persistent VMB infestations have been previously recorded. In addition to collecting novel records of VMB infestation, within-vineyard data on pesticide application, use of mating disruption, and prevalence of infestation are being collected.

Select uninfested and infested vineyards, including those containing novel infestations detected in 2018, will be surveyed in Summer 2019 to confirm infestation status. We will then compare the infestation status of these select vineyards relative to predicted habitat suitability, VMB management, and the distance of each surveyed vineyard to the nearest prior VMB detection in the previous year. This analysis will allow us to assses the explanatory power of VMB habitat suitability predictions and invasion kernels from prior detections, and to refine predictions for the areas most at risk to VMB infestation in the near future.

PROJECT PUBLICATIONS AND PRESENTATIONS

Publications

Daugherty, M.P., Cooper, M., and T.E. Schartel. 2018. Quantifying vine mealybug spatiotemporal dynamics: assessing invasion risk to refine management strategies. Pp 189-196 in *Symposium Proceedings, 2018 Pierce's Disease Research Symposium Proceedings*. California Department of Food and Agriculture. https://www.cdfa.ca.gov/pdcp/research.html

Presentations

Schartel, T.E., M. Cooper, and M. Daugherty. 2018. Increased understanding of vine mealybug (*Planococcus ficus* [Signoret]) invasion of Napa County informs management strategies. Proceedings of the 2018 Pierce's Disease Symposium. San Diego, CA. December 17-19. (*Poster*)

Schartel, T.E., M. Cooper, and M. Daugherty. 2018. Quantifying vine mealybug spatio-temporal dynamics: assessing invasion risk to refine management strategies. Proceedings of the 2018 Pierce's Disease Symposium. San Diego, CA. December 17-19.

Schartel, T.E., M. Cooper, and M. Daugherty. 2018. Data- and model-driven tools for improving management of invasive pests. Current Issues in Vineyard Health Symposium. University of California, Davis. November 29. (*Invited*)

Schartel, T.E., M. Cooper, and M. Daugherty. 2018. Increased understanding of vine mealybug (*Planococcus ficus* [Signoret]) invasion of Napa County informs management strategies. Entomological Society of America annual meeting, Vancouver, BC, Canada. November 11-14.

RESEARCH RELEVANCE STATEMENT

Better understanding of the factors driving VMB invasion is needed to curtail its ongoing range expansion in California, continued risk of introduction into novel regions of the US, and expense of management efforts. For this research project, survey data on 2012-16 VMB occurrence will be used to quantify spatiotemporal patterns in VMB occurrence, identify factors underlying hot spots of VMB occurrence/activity, characterize factors associated with VMB establishment, and clarify pathways that contribute to VMB spread in Napa County, California. This work will thereby help explain infestation patterns of this pest and identify areas at risk of infestation in the future. An improved understanding of the directionality and rate of VMB spread, as well as the pathways by which this insect disperses naturally or is moved by human activity, also will inform regulatory steps and direct educational efforts toward mitigating spread by targeted risk reduction strategies. Ultimately, such information is critical for developing a statewide response to this important vineyard pest.

LAYPERSON SUMMARY OF PROJECT ACCOMPLISHMENTS

Analysis of trapping records in Napa County indicate that the area affected by VMB's invasion continues to increase, with more than a 3-fold increase in the number of traps recording VMB between 2012 and 2017. Estimates of yearly spread range from approximately 100 to nearly 900 m, with patterns of spread that are highly idiosyncratic. Areas of VMB infestation are also highly clustered, with hotspots in activity within the central portion of Napa Valley between Napa and St. Helena that are increasing over time. Moreover, geospatial modeling suggests that the locations of these hotspots are not random. VMB infestation level depends on vineyard environmental characteristics (e.g., elevation, preciptation) and on factors associated within human activity (e.g., proximity to vineyards). These analyses have been used to predict those areas of Napa County not currently affected that are at highest risk to VMB infestation in the near future, the results of which have been shared with the Napa County Winegrape Pest & Disease Control District to guide their ongoing VMB monitoring efforts.

STATUS OF FUNDS

All activities for the first two objectives were completed in the last project period. Due to a delay in finding a sufficient number of field sites required for Objective 3, we were not able to complete that objective last season, as originally planned. As a result, a portion of funds assoicated with that objective remain. We anticipate requesting an extension to complete that objective, and expend remaining funds, over the coming field season.

SUMMARY AND STATUS OF INTELLECTUAL PROPERTY ASSOCIATED WITH THE PROJECT

No intellectual property is anticipated associated with the project.

CONCLUSIONS

Our findings indicate that VMB invasion of Napa County is well beyond the initial invasion stages and is actively spreading throughout this region. Future VMB spread may continue to occur via natural and/or human-assisted pathways at rates upwards of 850m per year. We detected substantial heterogeneity in both the distribution of statistically significant hotspots of VMB detections and estimated habitat suitability for VMB over the study region. The amount of precipitation in the driest month, elevation, and trap distance to nearest winery were identified as the most important and strongly associated predictors of habitat suitability for VMB.

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